Gross primary productivity and aquatic plant biomass: Indicators of divergence in two constructed wetlands

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Introduction

Recently, there has been growing pressure in the USA to restore drained wetlands, and to create new wetlands to replace wetlands lost to human encroachment. This growing pressure to reinstate lost wetlands in the USA stems in part from the recognition of the importance of wetlands to our ecosystem (Mitsch and Gosselink 1993), as well as due to the no net loss policy instilled by the National Wetlands Policy Forum in 1988 (National Wetlands Policy Forum 1988 cited in Mitsch and Gosselink, 1993). In response to the no net loss policy, several new wetlands have been constructed in the USA which serve a variety of purposes, i.e., wastewater treatment (Vincent, 1994; Thomas et al., 1995; Greenway and Woolley, 1999), and habitat restoration, such as the Des Plaines River Wetlands Demonstration Project (Fennessy et al., 1994), but seldom has the motivation been to increase our knowledge of these systems.

The Olentangy River Wetland Research Park (ORWRP) consists of two constructed, experimental wetlands with similar morphology and with a shared water inflow coming from the Olentangy River (Mitsch et al., 1998). The main difference between the two wetlands is that one wetland was artificially planted with a variety of emergent macrophytes (Wetland 1) and the other wetland (Wetland 2) was naturally colonized by plant propagules (Mitsch et al., 1998). These two wetlands have been the focus of a multitude of studies looking at changes occurring over time and comparing different parameters between the wetlands, such as the algal community (Deal, 1995; Deal and Kantz, 1996), soil development (Nairn and Mitsch, 1996), nutrient concentration and water productivity (e.g., Pahys et al., 1998).

Other studies have looked at whether the two wetlands were diverging or converging with respect to selected parameters (i.e., emergent macrophyte community, algal community, nutrient retention; Mitsch et al. 1998; Mitsch et al. 1999). These studies have varied in their conclusions due to the almost yearly fluctuation of the wetlands between divergence and convergence. The most recent study suggests that the two wetlands are diverging (Mitsch et al. 1999). This conclusion is based on a decrease in the number of similar parameters, 7 out of 9 similar parameters in 1998 in comparison to 8 out of 9 similar parameters in 1997, and on the difference in macrophyte community between the two wetlands (Mitsch et al. 1999). The parameters that differed among the two wetlands in 1998 were pH and conductivity, and it was suggested that a divergence in macrophyte community, productivity and biogeochemistry might occur in subsequent years (Mitsch et al. 1999).

The purpose of this study was to test whether Wetland 1 and Wetland 2 showed evidence of further divergence with respect to their gross primary productivity and in their aquatic plant biomass. Furthermore, the gross primary productivity and aquatic plant biomass were compared among inflow, middle, and outflow basins within each wetland, and any observed trends were compared between wetlands.

Methods

Study site

This study was conducted at the two kidney-shaped 1-ha basins in the ORWRP (Figure 1). Both wetlands were designed with deeper water sections located in the north, central, and southern portions of the basins and gently sloping topography to allow gradients from deep water through transitional to upland zones. The open water area of the wetlands is subdivided into 3 deep (approx. 60 cm) basins, inflow, middle and outflow, all surrounded by emergent macrophytes. Both wetlands receive water pumped at controlled rates from the nearby Olentangy River. Water enters these basins at their northern end, flows southward, and exits through the south ends of the basins where water returns to the Olentangy River.

Aquatic vegetation

All three basins in both wetlands were sampled for free-floating plant species, algae species and submerged plant species. To obtain a representative sample of each vegetation type from each basin, 8 samples were collected per basin using a circular quadrate (0.05 m^2). The quadrates were evenly spaced throughout the basins along both sides of the central boardwalk traversing all basins (1-8; Figure 1). Within each quadrate, all the duckweed species were

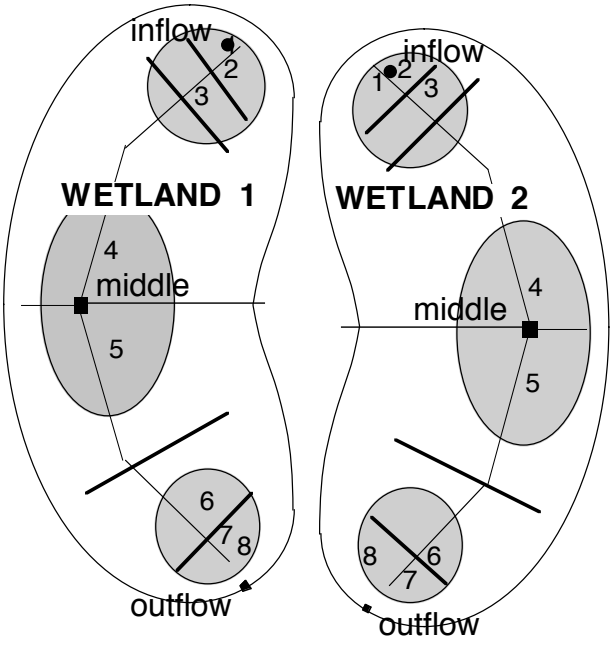

Figure 1. The two constructed experimental wetlands at the ORWRP, Wetland 1 and Wetland 2, showing the location of vegetation sampling stations.

collected using a sieve, and the algae and submerged plant species were collected by hand. After collection the duckweed, algae, and submerged plant species were placed in separate plastic bags in a cooler on ice and brought back to the laboratory.

Each sample was rinsed twice with tap water and finally with distilled water to remove mud, snails, and other particular matters. Algae and plant samples that appeared to be different in color or texture from each quadrate were placed on a slide with a drop of water, covered with a 22-mm^2 coverslip, and examined under a microscope at 100x magnification. Two keys were used to identify the genera of the algae and submerged vegetation (Prescott, 1962 and Fassett, 1957 respectively). To determine the dry weight of the samples, the clean samples were placed in pre-weighed weighing dishes (for duckweed and algal mat) or wrapped with aluminum foils (for submerged plants), then placed in a drying oven at 75 °C for over 48 hours. Immediately after the samples were taken out of the oven, they were transferred to a dessicator to cool down. The dry weight of each sample was measured using an analytical balance.

Community Primary Productivity

Dawn-dusk-dawn measurements of diurnal changes in dissolved oxygen (DO) were used to estimate the community primary productivity. This method is based on the principle that the photosynthesis of all autotrophs including mostly phytoplankton, algal mats, periphyton, and submerged vascular plants will contribute to the DO increase in the water column, while the respiration of all living organisms and non-living organic matter will reduce the DO. During the daytime, the DO change in the water column is a net result of photosynthesis and respiration. At night when photosynthesis is completely stopped, the DO change is caused exclusively by respiration. The calculation procedures of the primary productivity and respiration are described by Hall and Moll (1975) assuming constant respiration throughout the day and no net oxygen diffusion.

From October 11 to 16, 1999, dawn-dusk-dawn DO and water quality parameters including temperature, redox, pH, and conductivity were measured at approximately 0.3 meter below the water surface at the inflow pipe, two locations near the inflow, middle, and outflow, and one location at the outflow pipe (Figure 1). A Hydrolab Surveyor 3 Water Quality Logging System (Hydrolab Corp., Austin, TX) was used for these measurements. It was calibrated and recharged prior to use.

Solar radiation was measured at half-hour intervals with a pyranometer (Model Li-200SA) and automatically recorded by a Unidata Model 6003B portable data logger at the ORWRP weather station. Solar efficiency was calculated assuming: i) a carbon/oxygen conversion factor of 0.375; ii) a gram of fixed carbon equivalent to 10 kcal of energy; and iii) an average total solar radiation received during October 11 to 16, 1999 of 5010 kcal/m^2-day. The solar efficiencies of the three basins in each wetland were calculated using Eq. (1).

$$\text{Solar Efficiency}(\%) = [\text{GPP} / \text{Solar Radiation}] \times 100 \quad (1)$$

where

GPP = kcal/$m^2 day^{-1}$

Solar Radiation = kcal/$m^2 day^{-1}$

Measurements of in-vivo chlorophyll, turbidity, and nutrients

Chlorophyll was measured in-vivo on October 9, 1999 by nine groups of students enrolled in the water quality class (Fall Quarter, 1999). Water samples were taken at various locations in the wetlands and in the river and discharge waters. Only data collected at the middle and outflow of each wetland were presented in this report. Chlorophyll, turbidity, and nutrient content (nitrate and reactive phosphorus) were measured in the field using a Turner Designs 10-AU fluorometer, a Hach Ratio Turbidimeter, and a Hach DR/700 Colorimeter, respectively. Fluorescence analysis of chlorophyll is one of the most widely used and sensitive methods for monitoring and mapping phytoplankton in surface water (Hall and Moll, 1975). When chlorophyll-containing phytoplankton is small enough, the fluorescence intensity is directly proportional to the concentration of chlorophyll in the sample. However, because the standardization of the fluorometer against a spectrophotometer was not performed

on that day, data presented here only provide a relative reading of chlorophyll in water, not the actual concentration with a unit of μg/L. Distilled water was used as a blank sample.

Statistical Analysis

Systat version 9.0 was used to analyze all data. Non-parametric tests were used to analyze the data sets due to the violation of assumptions of the parametric test (Sokal and Rohlf 1995). A matched Wilcoxon test was used to compare the data of the two wetlands. If a significant difference was found between wetlands, then a Mann-Whitney U-test was used to locate which pairs of basins differed between the two wetlands (inflow versus inflow, middle versus middle, or outflow versus outflow). A Kruskal-Wallis test was used to test whether the three basins within a wetland differed from one another. If basins in a wetland were found to be significantly different, then a Mann-Whitney U-test was used to identify which pairs differed from one another (inflow versus middle, inflow versus outflow, or middle versus outflow). To correct for multiple comparisons, the sequential Bonferroni procedure was used (Rice 1989). Graphs were plotted using mean and standard error to facilitate interpretation of results.

Results

Aquatic vegetation

Free-floating duckweed (*Lemna* sp.), the filamentous algae *Cladophora* sp., and the submerged vegetation plant, *Najas* sp. were found in both wetlands. The sample size for wetland comparison was 24 per plant species, and the sample size for between basin comparisons was 8 per plant species. The two wetlands differ significantly in the amount of biomass for each of the three plant species. There was a significantly larger amount of *Lemna* sp. (p=0.00), among the basins (Wetland 1: p=0.00; Wetland 2: p=0.00), and *Cladophora* sp. (Wetland 1: p=0.00; Wetland 2: p=0.00; Figure 2). As to the amount of *Najas* sp., a significant difference existed among the basins in Wetland 1(p<0.001) but not in Wetland 2 (p=0.37). In Wetland 1, the inflow basin had a greater amount of duckweed and *Chlorophora* sp. than the middle (p=0.001 and p=0.001, respectively) and the outflow basins (p=0.00 and p=0.00, respectively). The middle basin of Wetland 1 contained more duckweed and *Chlorophora* sp. than the outflow basin (p=0.00 and p=0.00, respectively). In Wetland 1, outflow and middle basins had higher biomass than the inflow of *Najas* sp. (p=0.00), but the inflow and middle basins did not differ from one another (p=1.0). In Wetland 2, the inflow basin had a larger amount of duckweed and *Chlorophora* sp. than the middle (p=0.00 and p=0.00, respectively) and outflow basin (p= 0.00 and p=0.00, respectively). The middle and the outflow basins did not differ in the amount of biomass of duckweed or *Cladophora* sp. (p=1.0 and p=1.0, respectively). The amount of *Najas* sp. did not differ between the basins (inflow-middle: p=1.0; inflow-outflow: p=0.32; middle-outflow: p=0.32).

Although sampling of algae and submerged vegetation only revealed the presence of *Chlorophora* sp. and *Najas* sp., respectively, studies done in previous years (Deal 1995; Kantz and Deal 1999) and during the growing season of 1999 (M. Liptak pers. comm.) have revealed the presence of many other species. This difference is probably due to the sampling having taken place in late October, when several species of algae and submerged plants have already died.

Community Primary Productivity

Typical diurnal pattern of DO and rate of DO change in the wetlands were calculated and plotted in Figure 3. The area under the positive rate of change represents net primary productivity; the area under the negative rate of change represents night respiration. Assuming the daytime respiration rate equals the night respiration rate and the production at night is negligible, the GPP was calculated by integrating the shaded areas as shown in Figure 3. Water quality data for each sampling point are shown in Table 1.

A sample size of 30 GPP values per wetland was used for between wetland comparison, and a sample size of 10 GPP values per each basin was used for between basin comparisons. The two wetlands did not differ in their GPP during the sampling period (p=0.30**;** Figure 4a). The basins within each wetland did differ significantly for Wetland 1 (p=0.00) and for Wetland 2 (p=0.00). In Wetland 1, both the inflow basin (p=0.00) and the middle basin (p=0.001) had lower GPPs than the outflow basin. The inflow and middle basins did not differ significantly in their GPPs (p=0.23), although the GPP for the inflow was lower. In Wetland 2 the GPP value for the inflow basin was significantly lower than the GPP for the middle (p=0.00) and for the outflow basins (p=0.002), whereas the middle and the outflow basins did not differ significantly from one another (p=0.23). The solar efficiency followed the same trend as the GPP (Figure 4c). The solar efficiencies of Wetland 1 were 0.11% in the inflow, 0.15% in the middle, and 0.42% in the outflow with an average of 0.23%; the solar efficiencies of Wetland 2 were 0.14% in the inflow, 0.35% in the middle, and 0.33% in the outflow with an average of 0.27%. These data were much lower than the one-time measurement by Yu et al. (1997) in October 1996 (1.06%), but were very close to what Pahys et al. (1998) measured in October 1997 (0.1 to 0.3%).

The ratio of GPP to respiration (GPP/R) can be used as an index of the net community production of the wetland. The higher the ratio, the higher the net community production achieved. Both wetlands had a GPP/R ratio close to 1 (Figure 3b), indicating no net community production in either wetland during this season of the year,

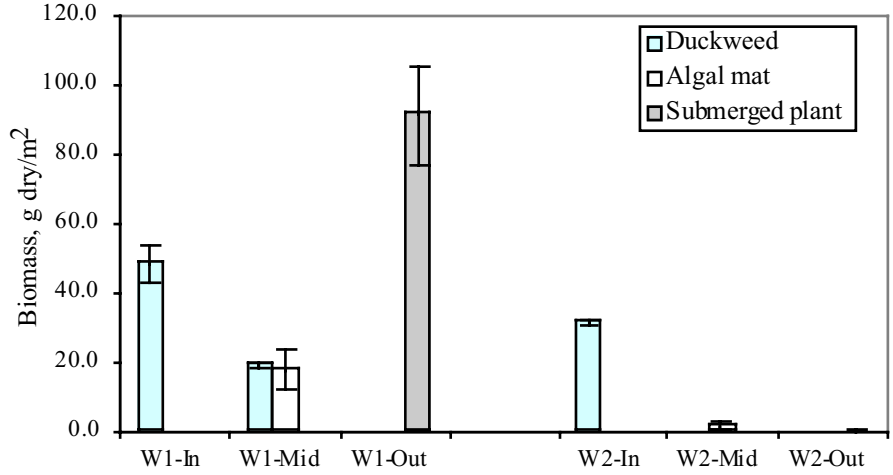

Figure 2.The dry plant biomass for each wetland at the ORWRP.

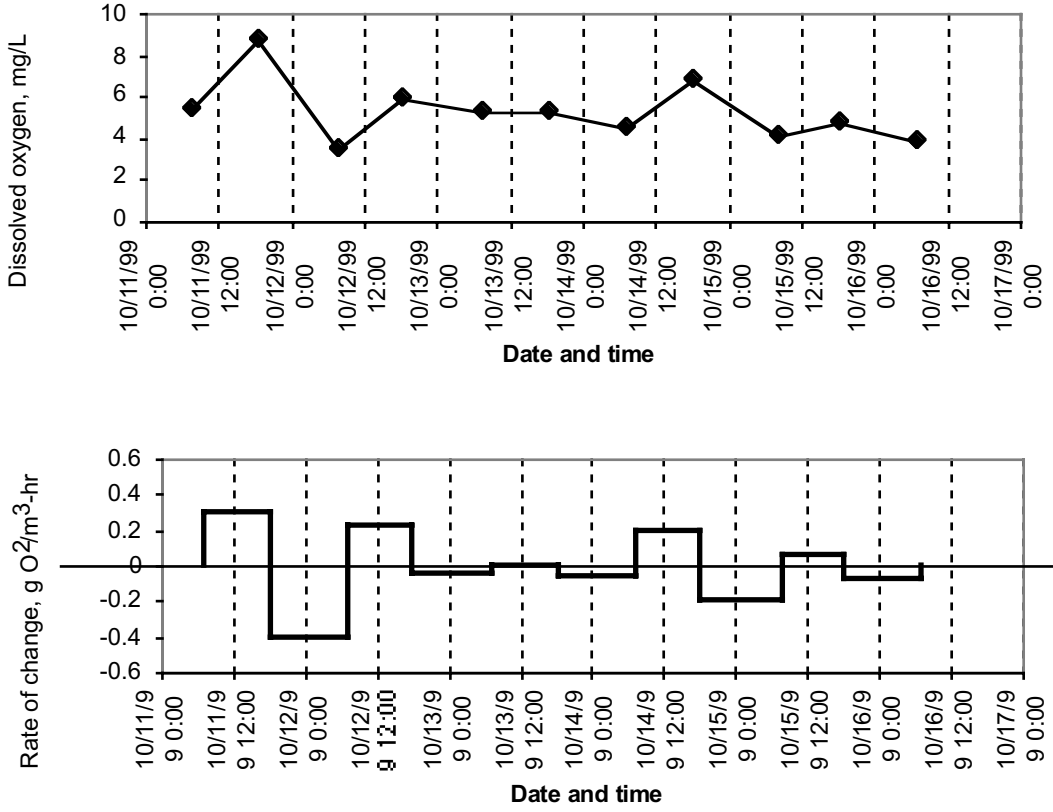

Figure 3. Typical diurnal pattern of dissolved oxygen (DO) and rate of DO change in Wetland 1.

presumably due to slower aquatic plant growth and higher organic matter decomposition compared to the growing season.

Measurements of in-vivo chlorophyll, turbidity, and nutrients

Based on the measurements on October 9, 1999, the water in the middle basins had higher nutrient levels, water turbidity, and chlorophyll contents than the water in the outflow basins (Figure 5), consistent with previous studies done at the same wetlands (Mitsch et al., 1996; Wu and Mitsch, 1998; Mitsch et al., 1999). Nutrient and turbidity removal patterns have been observed continuously for the last 5 years at the same wetlands (Mitsch, et al., 1999), signifying the role of wetlands as a nutrient sink and transformer (Mitsch and Gosselink, 1993). No significant differences were detected in nutrient

Table 1. Average ± standard error of selected water quality data of October 1999 for Wetlands 1 and 2.

Location[a]	Temp °C	DO mg/L	Cond. µs/cm	pH	Redox mV	Temp °C	DO mg/L	Cond. µs/cm	pH	Redox mV
			W1					*W2*		
1	15.75±0.29	6.38±0.14	540±13	7.79±0.06	547±14	15.68±0.28	6.34±0.19	545±13	7.66±0.09	495±11
2	15.07±0.54	5.29±0.45	519±11	6.92±0.66	512±11	15.32±0.71	4.87±0.65	529±16	7.53±0.11	495±17
3	14.41±0.72	4.23±0.62	533±13	7.39±0.07	491±18	14.99±0.97	4.96±0.68	528±13	7.57±0.14	490±18
4	14.74±1.19	4.92±0.65	539±12	7.62±0.08	486±27	14.58±1.18	6.38±1.33	522±14	7.96±0.28	454±20
5	14.71±1.03	5.38±0.67	560±12	7.79±0.19	465±20	15.36±1.20	8.47±1.59	513±10	7.81±0.16	465±17
6	15.07±1.08	6.71±1.81	518±10	7.94±0.21	463±18	14.74±1.16	8.16±1.45	524±10	7.96±0.18	461±17
7	14.49±0.96	6.89±1.98	506±11	7.92±0.22	474±22	14.62±0.98	8.16±1.50	521±13	7.97±0.18	467±22
8	14.64±0.92	6.02±0.86	543±12	7.71±0.14	464±24	14.28±1.22	7.49±0.91	547±8	7.94±0.19	472±23

(a) See Figure 1 for locations.

content and chlorophyll between Wetland 1 and Wetland 2; however, significant difference existed between the middle and the outflow in each wetland.

Nutrient and light conditions are the major factors affecting phytoplankton primary productivity (Wetzel, 1983). As expected, the phytoplankton biomass, as measured as chlorophyll in this study, decreased from the middle to the outflow in both wetlands (Figure 5). However, because the chlorophyll concentration was not calibrated against standards during the field measurements, the data only provided general trends in spatial variations of phytoplankton productivity rather than the actual phytoplankton productivity in the wetlands. According to Yu et al. (1997), the phytoplankton GPP measured by the light-dark bottle method suggested no significant difference between the inflow and the outflow. The average phytoplankton production accounted for 17% of the total water column GPP (Yu, et al., 1997).

Discussion

Aquatic vegetation

In general, both wetlands showed a similar spatial pattern in each vegetation type from the inflow to the outflow. Because duckweed tends to be abundant in water with high nutrient concentrations while submerged aquatic vegetation are more characteristic of low nutrient conditions (Janse and Puijenbroek, 1998), the decrease in nutrient concentrations across basins resulted in the observed shift in vegetation type. Also, duckweed, in growing in a uniform layer over open water (Janse and Puijenbroek, 1998), might reduce the amount of light that penetrates into the water column; thereby inhibiting the growth of the submerged vegetation, algae and other phytoplankton.

The difference in the amount of plant biomass between the two wetlands might also be related to differences in nutrient concentrations between wetlands, however, this data was not available. Another possible explanation for the difference in plant biomass may be related to wildlife activities. For example grazing by tadpoles and snails on *Cladophora* sp. algae (Brönmark et al., 1991) could reduce the algae biomass if more tadpoles and snails are found in Wetland 2. Waterfowl grazing and disturbance through their activities may also impact the abundance of aquatic vegetation. More waterfowl feces were observed on the boardwalk of Wetland 2, indicating a higher use of Wetland 2 by waterfowl. The grazing habits of the waterfowl, i.e., feeding on submerged vegetation (Schloesser and Manny, 1990; McKnight 1995, 1998), and the disturbance created by their activities, i.e., swimming and diving below the water surface, may explain the lower plant biomass in Wetland 2 than in Wetland 1. Another explanation might be that the difference in vegetation may result in one wetland being more attractive to wildlife. For example, the higher abundance of *Typha* sp. in Wetland 2, might provide more cover for ducks thereby making this wetland more attractive. In addition, the shading created by the robust biomass of *Typha* sp. might reduce light penetrating into the water column which would affect plant biomass in that wetland.

Community Productivity

The GPP did not differ between Wetland 1 and Wetland 2; however, the basins within a wetland did have significant differences in GPP. The GPP appears to increase from the inflow basin to the outflow basin in both wetlands, except that in Wetland 2 the GPP of the middle basin was slightly higher than that of the outflow. This spatial pattern was consistent with Pahys's study (1998) in which the GPP was generally higher at the outflow than that in the middle in both July and October 1997.

The difference in the GPP trend across the basins within each wetland may be related to the difference in aquatic vegetation biomass. Discounting the biomass of

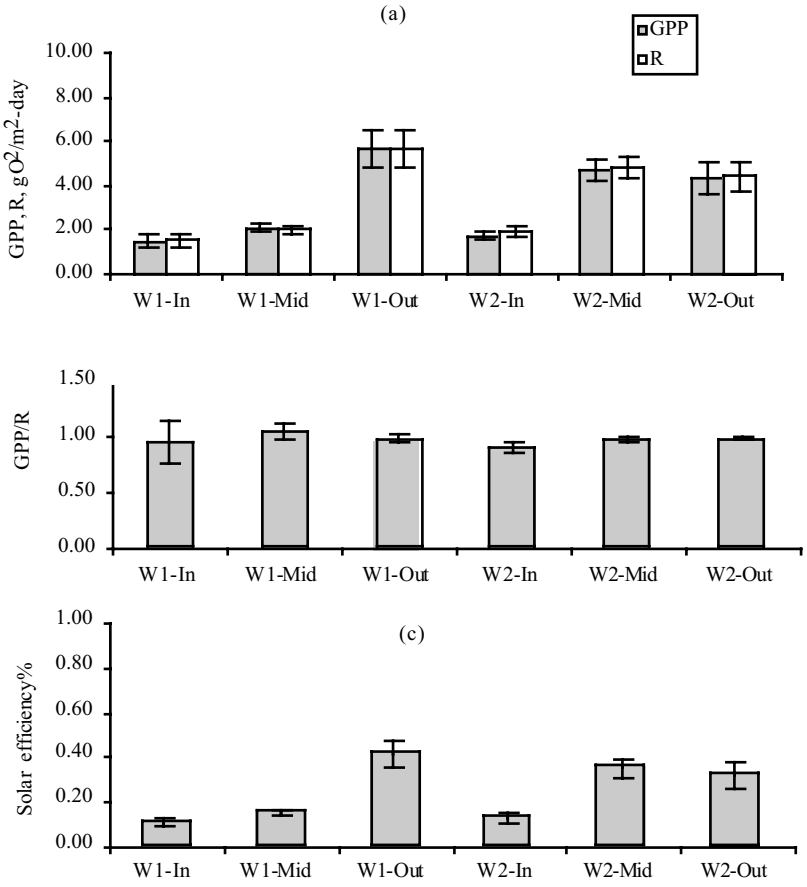

Figure 4. The gross primary productivity (GPP), respiration (R), GPP/R, and solar efficiency measured at the inflow basin (In), middle basin (Mid), and outflow basin (Out) of the two ORWRP wetlands (W1, W2).

duckweed, (free-floating plants do not contribute significantly to the water column dissolved oxygen), Wetland 1 had an increasing amount of aquatic plant biomass from the inflow basin to the outflow basin, thus corresponding to the increasing GPP trend. Wetland 2 had the lowest amount of aquatic plant biomass at the inflow, and the highest amount of biomass at the middle. The GPP follows the trend illustrated by the aquatic plant biomass, with the middle basin having the highest GPP.

Phytoplankton are also contributors to the water column productivity (Yu et al., 1997). The abundance of phytoplankton in the water column was related to the amount of chlorophyll (Wu and Mitsch, 1998). In this study phytoplankton appear to decrease from the middle to the outflow basins in both wetlands. Although phytoplankton biomass was not quantified in the inflow basin, it may have been lower than the middle and outflow basins due to the shading effect of duckweed, resulting in the lowest GPP for the inflow basin. Higher phytoplankton biomass in the middle basin might explain the occurrence of the highest GPP in that basin for Wetland 2. In Wetland 1, the phytoplankton biomass might not be a major contributor to the GPP because of the high abundance of aquatic vegetation biomass.

Productivity is influenced by water quality and also affects water quality. No significant difference was detected between the water quality of the two wetlands in terms of nutrients (Figure 2), temperature, conductivity, pH and redox (Table 1), consistent with previous measurements by Mitsch et al. (1999). Similar water quality data might explain why the two wetlands had similar average GPP and respiration. On the other hand, high productivity could result in high pH and turbidity in water (Vorwerk and Mitsch 1998); as observed in this study with the concurrent increase in pH and GPP from the inflow to the outflow.

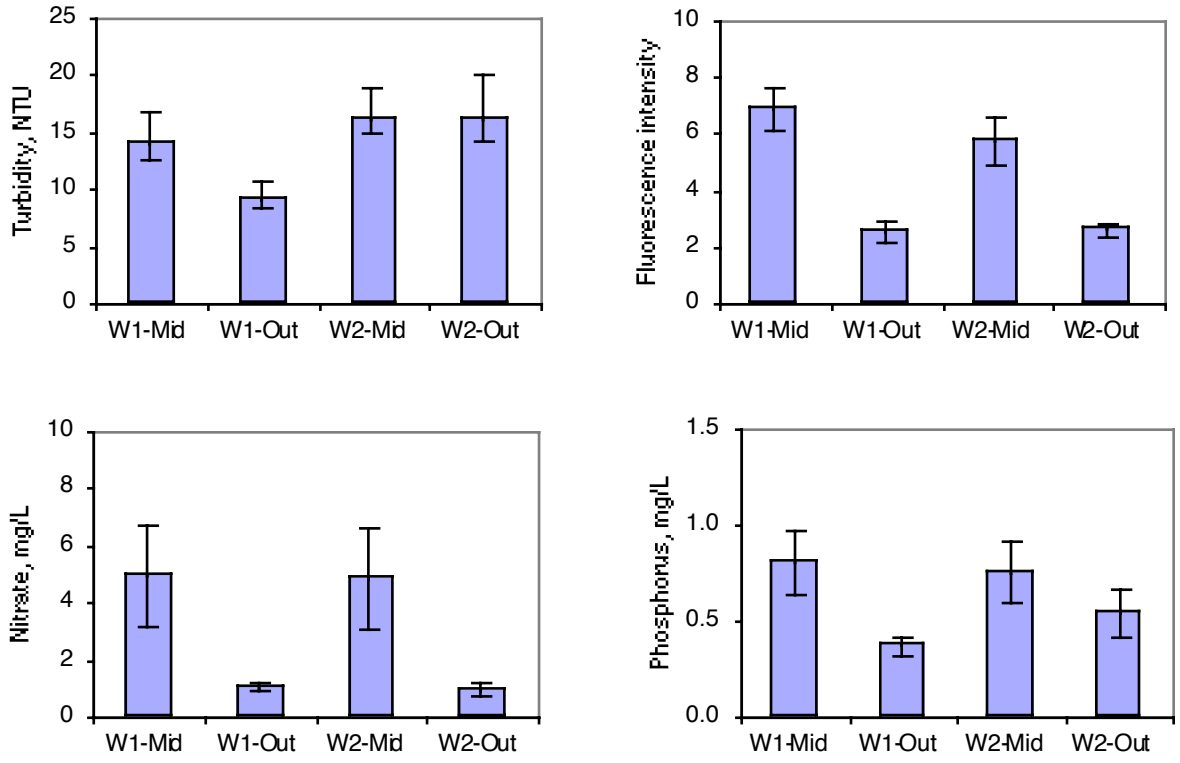

Figure 5. Measurement of turbidity, chlorophyll, nitrate, and soluble reactive phosphorus in the middle and outflow of Wetland 1 and Wetland 2 on October 9, 1999.

Conclusion

Gross primary productivity is contributed by phytoplankton, periphyton, metaphyton, and submerged plants. Both wetlands showed no significant differences in gross primary productivity and phytoplankton productivity; however, Wetland 1 had significantly greater algal mats and submerged plants than Wetland 2. Within each wetland, GPP and aquatic plant biomass increased from the inflow to the outflow while phytoplankton productivity decreased from the middle to the outflow basins. The significant difference in aquatic plant biomass between the wetlands suggests that the wetlands may be diverging, and a difference in gross primary productivity may be expected to continue. In addition, the different use of wetlands by wildlife might be responsible for the observed divergence in vegetation and/or serve as an indication of divergence.

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References

Brönmark, C., S.D. Rundle and A. Erlandsson. 1991. Interactions between freshwater snails and tadpoles: competition and facilitation. Oecologia 87: 8-18.

Deal, R. 1995. Algal identification in newly constructed wetlands. In : Mitsch, W.J. (ed.). Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1995, The Ohio State University, Columbus, OH, pp. 69-71.

Deal, R. and J.A. Kantz, Jr. 1996. Seasonal and successional trends in algal diversity and population dynamics in constructed wetlands. In : Mitsch, W.J. (ed.). Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1995, The Ohio State University, Columbus, OH, pp. 137-140.

Fassett, N.C. 1957. A Manual of Aquatic Plants, 2nd edition. Wisconsin: The University of Wisconsin Press.

Fennessy, M.S., J.K. Cronk and W.J. Mitsch. 1994. Macrophyte productivity and community development in created freshwater wetlands under experimental hydrological conditions. Ecological Engineering 3: 469-484.

Greenway, M. and A. Woolley. 1999. Constructed wetlands in Queensland:performance efficiency and nutrient bioaccumulation. Ecological Engineering 12: 39-55.

Hall, C.A.S. and R. Moll. 1975. Methods of assessing aquatic primary productivity.In: Lieth, H. and R.H. Whittaker. (eds.). Primary Productivity of the biosphere. New York : Springer-Varlag New York Inc. pp. 19-54.

Janse, J.H. and P.J.T.M. Van Puijenbroek. 1998. Effects of eutrophication in drainage ditches. Environmental Pollution 102(S1): 547-552.

Kantz, J. Jr. and R. Deal. 1999. Comparison of macroalgal dominants in the two Olentangy River experimental wetland basins. In : Mitsch, W.J. and V. Bouchard (eds.). Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1998, The Ohio State University, Columbus, OH, pp. 77-78.

McKnight, S.K. 1995. Potential effects of Grass Carp herbivory on waterfowl foods. Journal of Wildlife Management 59(4): 720-727.

McKnight, S.K. 1998. Diet Selectivity of Gadwalls wintering in Alabama. Journal of Wildlife management 62(4): 1533-1543.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands, 2nd edition. New York: John Wiley and Sons, Inc. Pp. 722.

Mitsch, W.J., R.W. Nairn, X. Wu and A. Wehr. 1996. Water quality changes in Olentangy River water caused by the experimental wetlands at the Olentangy River Wetland Research Park – first year results. In: Mitsch, W.J. (ed.), Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1995, The Ohio State University, Columbus, OH, pp. 51-72.

Mitsch, W.J., N. Wang, V. Bouchard, M. Ford and K. Mohler. 1999. Biogeochemical and nutrient removal patterns of created riparian wetlands: fifth-year results. In: Mitsch, W.J. and V. Bouchard (eds.). Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1998, The Ohio State University, Columbus, OH, pp. 79-85.

Mitsch, W.J., X. Wu, R.W. Nairn, P.E. Weihe, N. Wang, R. Deal and C. Boucher. 1998. Creating and restoring wetlands. Bioscience 48(2): 1019-1030.

Nairn, R. and W.J. Mitsch. 1996. Physicochemical changes and genesis of soils in newly constructed wetlands. In: Mitsch, W.J. (ed.). Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1995, The Ohio State University, Columbus, OH, p. 103.

Pahys, K.E., V. Bouchard and W.J. Mitsch. 1998. Water column primary productivity in the experimental freshwater wetlands for July and October 1997. In: Mitsch, W.J. and V. Bouchard (eds.). Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1997, The Ohio State University, Columbus, OH, pp. 149-153.

Prescott, G.W. 1962. Algae of the Western Great Lakes area, 2nd ed. Dubuque, IA: Wm. C. Brown Company, Inc.

Rice, W. R. 1989. Analyzing tables of statistical tests. Evolution 43(1): 223-225.

Schloesser, D.W. and B.A. Manny. 1990. Decline of Wildcelery buds in the lower Detroit river, 1950-85. Journal of Wildlife Management. 54(1): 72-76.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry, 3rd ed. New York: W.H. freeman and Company.

Thomas, P.R., P. Glover and T. Kalaroopan. 1995. An evaluation of pollutant removal from secondarily treated sewage effluent using a constructed wetland system, Water Science and Technology 32: 87-93.

Vincent, G. 1994. Use of artificial wetlands for the treatment of recreational wastewater. Water Science and Technology 29: 67-70.

Vorwerk, N and W.J. Mitsch. 1998. Comparison of three years of pH values between planted and unplanted wetlands. In: Mitsch, W.J. (ed.), Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1997, The Ohio State University, Columbus, OH, pp. 97-104.

Wetzel, R.G. 1983. Limnology, 2nd edition. Saunders College Publishing. New York, NY. 767 p.

Wu, X. and W.J. Mitsch. 1998. Spatial and temporal patterns of algae in newly constructed freshwater wetlands. Wetlands 18(1): 9-20.

Yu, N., D.A. Culver and W.J. Mitsch. 1997. Phytoplankton primary productivity and community metabolism at the OSU Olentangy River Wetlands. In: Mitsch, W.J. (ed.). Olentangy River Wetland Research Park at The Ohio State University, Annual Report 1996, The Ohio State University, Columbus, OH, pp. 155-158.